Aerocapture as an Enabling Technology for Planetary Missions

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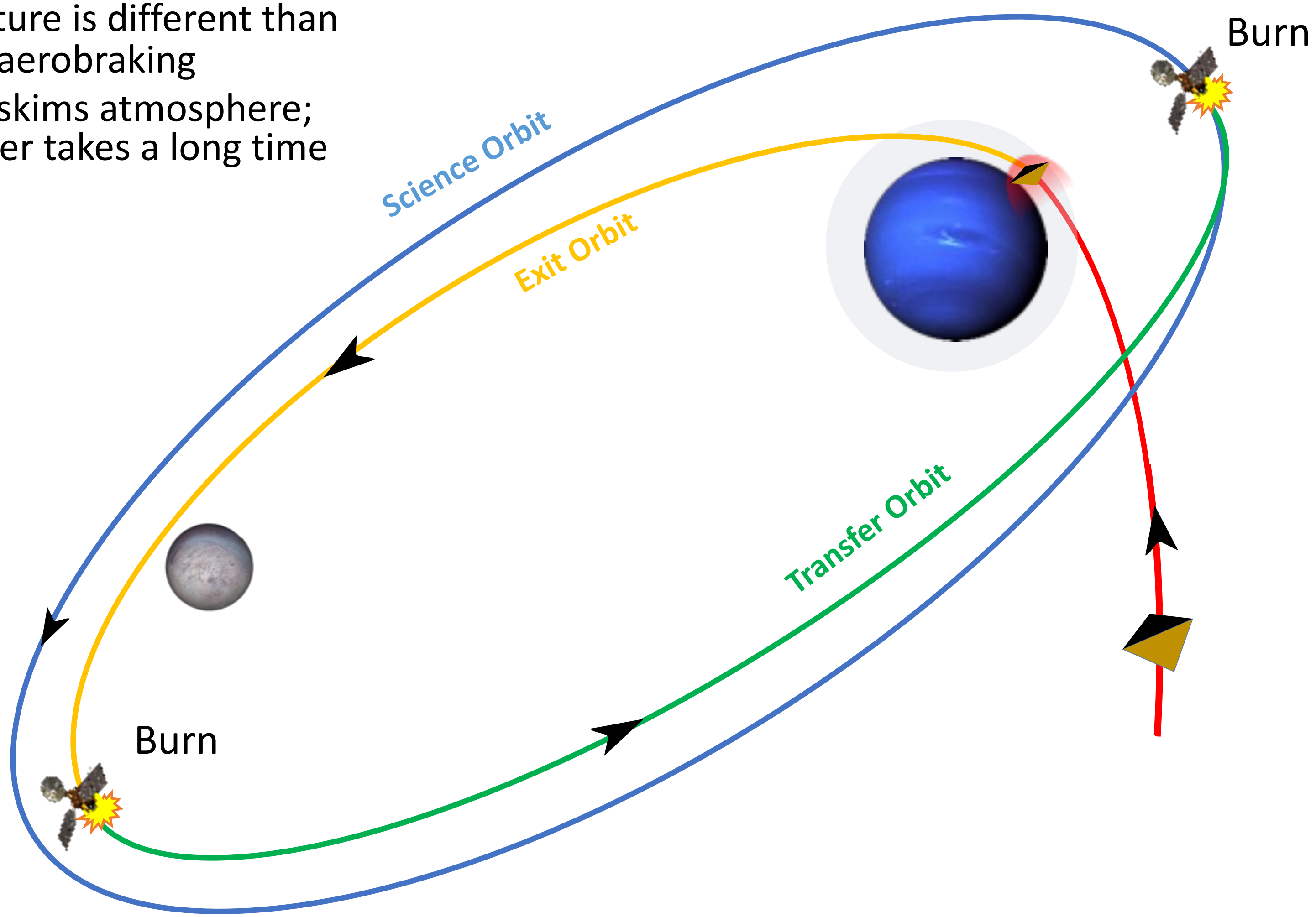
Outline

- What is aerocapture?
- Where can aerocapture help?
- How aerocapture designs have evolved
- Point Design: Uranus aerocapture
- Point Design: Small Satellites aerocapture

What is Aerocapture?

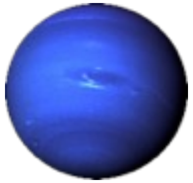
Aerocapture is different than aerobraking
Which skims atmosphere; maneuver takes a long time



Orbital maneuver where the drag from a single atmospheric pass provides deceleration for orbital insertion

Where Can Aerocapture Help Missions

Planetary Science: Uranus and Neptune



Typical Fully-Propulsive Mission

- **Need 50% or more mass** for fully-propulsive orbit insertion (requires ΔV of 1-2 km/s)
- Typical mission **require long cruise phase** (13-17 years)

Aerocapture Enabled Mission

- Reduced propellant need
- Savings used for **launch vehicle choice, launch opportunities, or increase on-orbit science payload**
- Aerocapture can enable faster interplanetary trajectories – **reduce trip time by 3-5 years**
- Fit a larger mission into a smaller funding cap. e.g., **Flagship class mission in New Frontiers cap**

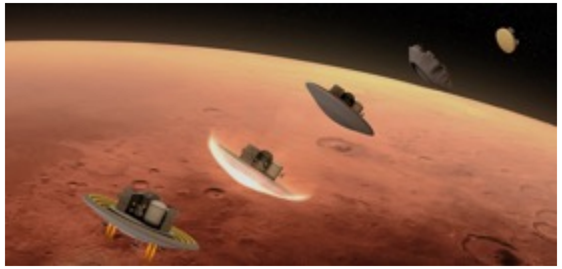
Aerocapture directly infusible to top destinations for the 2023-2032 Decadal Survey

SmallSat: Planetary SmallSat Missions

- Typically: Volume and mass constrained; propellant systems are a heavy burden
- Aerocapture systems: Can reduce necessary propellant – **50-80% more useful mass on-orbit** depending on the orbit

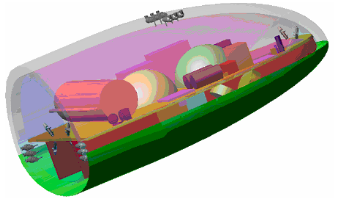
Human Exploration: Human-scale Mars Missions

- Human-scale missions could **reduce trip time** with a faster interplanetary trajectory and **increase on-orbit mass** compared to traditional orbit insertion

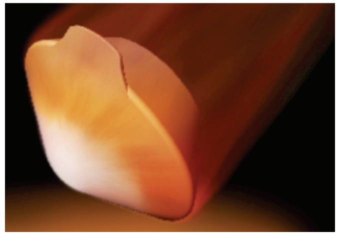


Capabilities that Enable Aerocapture

- **Previously**
  - Aerocapture needed new vehicles
  - Guidance, Navigation, and Control (GNC) and Thermal Protection System (TPS) material development needed

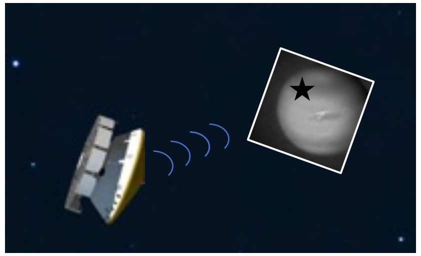


- **Developments in last 10-15 years matured components needed for aerocapture success**



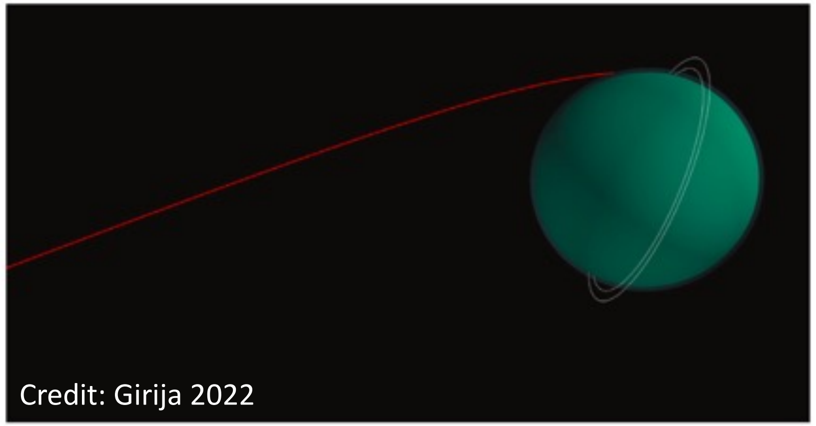
- **Advanced GNC**
  - Entry guidance successful on Mars Entry, Descent, and Landing (EDL) – Mars Science Laboratory and Mars 2020
  - Predictor-corrector guidance flew on Exploration Flight Test-1 and part of Artemis-1
  - Trim tab used on Chinese EDL mission to Mars in 2021

- **TPS for Aerocapture Environments**
  - PICA TPS has flight heritage (Stardust, MSL, Mars 2020) and HEEET (3MDCP) TPS has been chosen for flight projects (Mars Sample Return Earth Entry System)
  - Conformal PICA TPS might be a lightweight solution with performance for aerocapture



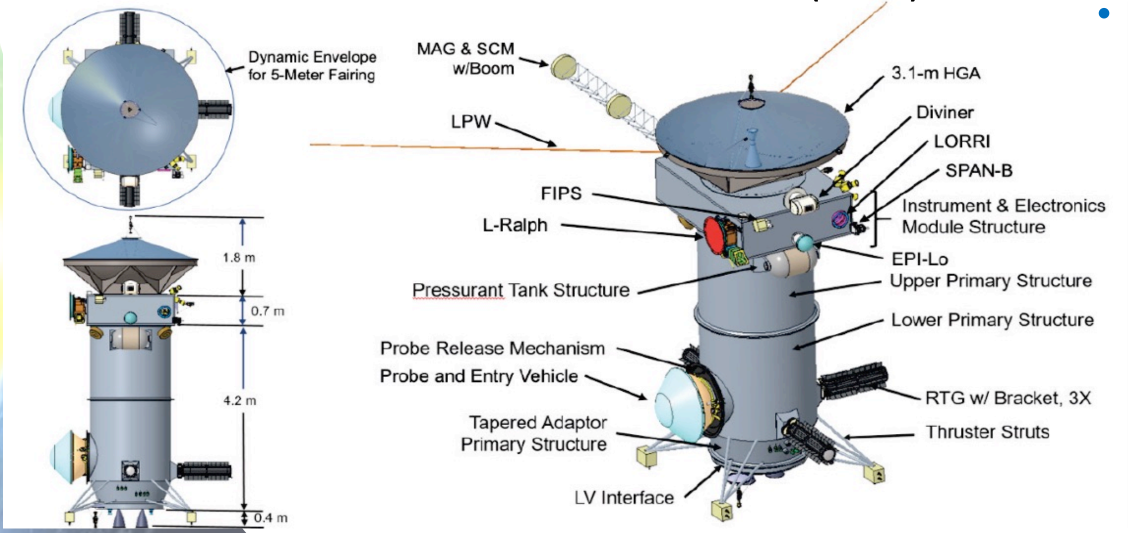
- **Optical Navigation (OpNAV) and Autonomous Navigation (AutoNAV)**
  - Improves navigation uncertainty for entry
  - Demonstrated in missions like Deep Space 1

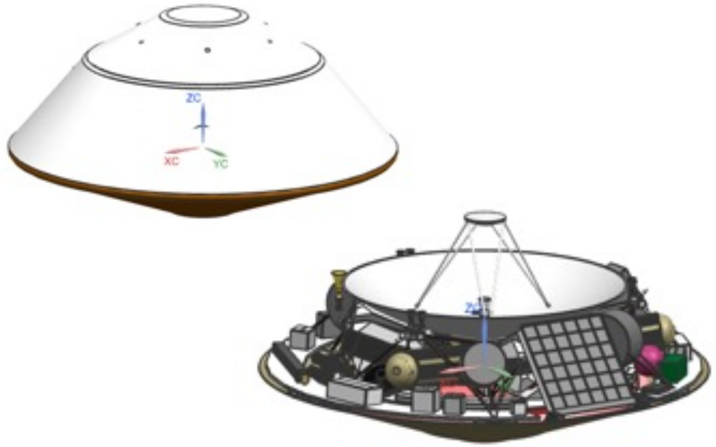
Uranus Aerocapture



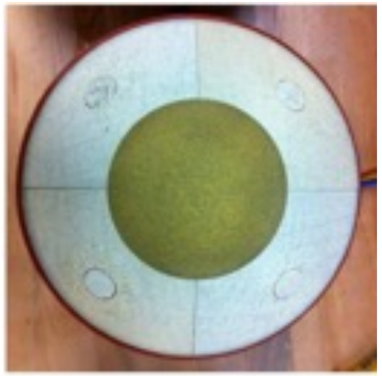
- 2021 Uranus Orbiter and Probe mission concept study influenced the 2023-2032 Planetary Decadal Survey choosing Uranus as the top flagship-class destination
  - 2031/2032 launch date; 13 years of transit
  - 1000 m/s ΔV for Uranus Orbit Insertion (1800 kg fuel)
  - 60-70% of launch mass is fuel
  - Nuclear power source lifespan degrades after 17 years
- Recent aerocapture studies have shown UOP payload can fit in heritage aeroshell and have feasible GNC and TPS solutions
  - Transit to Uranus in 7-9 years; save 1000 kg in fuel in orbit insertion
  - **Can we enable Flagship class science in New Frontiers budget?**

2021 Uranus Orbiter and Probe (UOP)





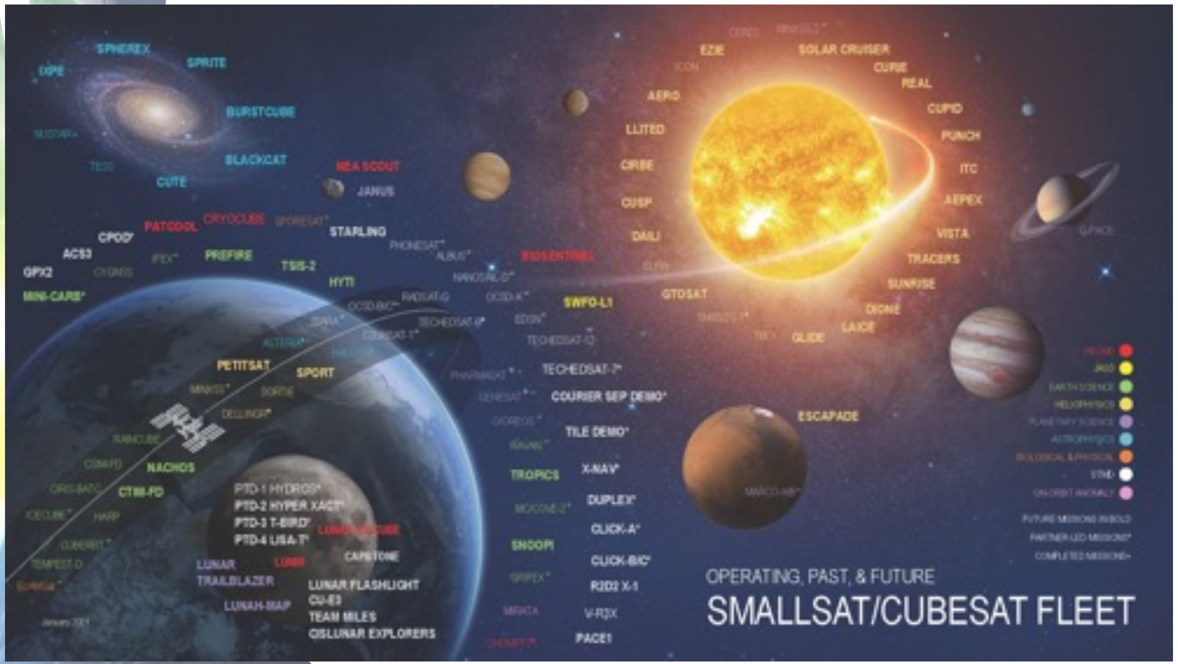
Conformal TPS

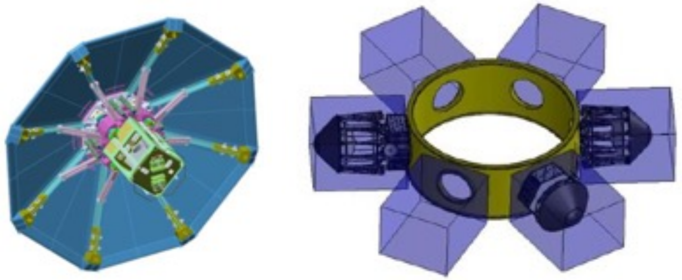


Small Satellite Aerocapture

- Planetary exploration using Small Sats will become more common
- Small Sats are constrained by volume; orbit insertion propellant tanks, fuel may limit abilities for planetary missions
- Aerocapture can improve volume and mass constraints for Small Sat orbit insertion
- Options like deployables (inflatable, mechanical) can further allow volume, mass efficient orbit insertion alternatives for Small Sats

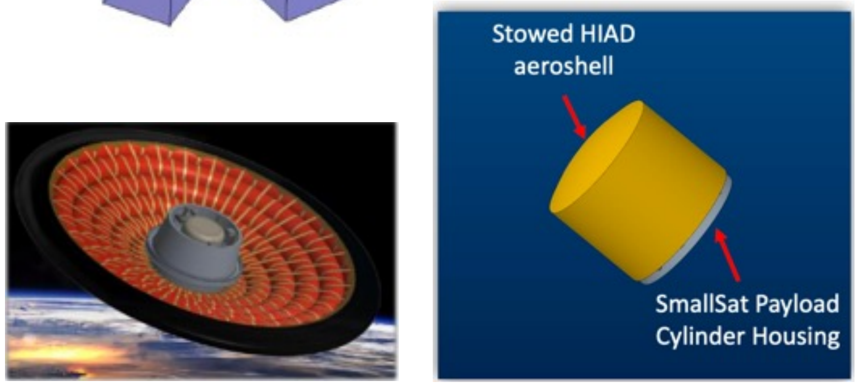
NASA Small Satellite Fleet





Mechanical Deployable Small Sat Configuration

Inflatable Deployable Small Sat Configuration



Summary

- Aerocapture can be mass, volume, and time-saving orbit insertion mechanism that uses atmospheric drag to capture spacecraft into orbit
- Aerocapture has potential usages in planetary science applications, orbit insertion for small satellites, and even for human exploration
- Recent advancements in GNC, TPS, and navigation have extended the capabilities of aerocapture
- Aerocapture is especially enabling for a Uranus flagship mission or small satellites

References

WHITE PAPER FOR THE
PLANETARY SCIENCE DECADAL SURVEY, 2023 - 2032

Aerocapture as an Enhancing Option for Ice Giants Missions

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1. Spin.Works S.A.
2. University of Colorado, Boulder
3. Georgia Institute of Technology
4. Analytical Mechanics Associates
5. NASA Ames Research Center
6. Jet Propulsion Laboratory/California Institute of Technology
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8. John Hopkins University/Applied Physics Laboratory
9. NASA Langley Research Center
10. Deimos Space (Spain)
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19. Kent State University
20. Aurora Technology B.V.
21. Mullard Space Science Laboratory, University College London
22. Institute of Structures and Design - German Aerospace Center (DLR)
23. Spacefaring Technologies Inc.
24. Hampton University
25. European Space Agency – ESTEC

White Paper Submitted to National Academy's Planetary Science Decadal Survey 2023-2032

- Aerocapture has appeared in the literature since the 1960's
- Three white papers on aerocapture were written for the 2022 Planetary Decadal Survey
  - Aerocapture for Ice Giants (Dutta et al.)
  - Aerogravity Assist to Enable Enceladus Missions (Tackett et al.)
  - Small Satellite Aerocapture (Austin et al.)

Dutta et al.

Tackett et al.

Austin et al.